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DELAMINATION STUDY WHEN DRILLING ON A CARBON C-ORTHOCRYL COMPOSITE USED IN ORTHOPEIDIC PROSTHESIS

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ABSTRACT

Carbon composites are popular in the construction of orthopedic devices and automobile construction applications due to their excellent strength-to-weight ratio and environmental compatibility. Also, these materials are widely utilized to reinforce, retrofit, and rehabilitate the production of orthopedic prostheses and medical devices, enhancing prosthesis strength and overall quality of life. However, the long-term performance and durability of carbon composites against machining settings remain inadequately understood, especially at the microscopic level. The microscopic degradation of carbon composites in orthopedic structures is a complex issue influenced by mechanical properties, environmental conditions, and manufacturing parameters. Understanding the damage mechanisms is essential for ensuring the reliability and safety of articulations throughout their intended lifespan. Consequently, there is an urgent need for a comprehensive investigation into the microscopic degradation of carbon composites in medical applications. This research aims to fill this critical knowledge gap by thoroughly examining microscopic degradation processes, with particular focus on delamination. By using advanced analytical techniques such as scanning electron microscopy, we intend to reveal morphological and mechanical changes at the microscale, including delamination and decohesion. Furthermore, this study will assess the impact of various mechanical and environmental factors on the degradation behavior of carbon composites, offering valuable insights into their long-term performance in prosthesis applications.



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I. INTRODUCTION

Because of their remarkable strength-to-weight ratio, corrosion resistance, and versatility when combined with various matrices, carbon fiber-reinforced polymer (CFRP) composites have attracted significant interest across several application areas. Recent studies offer several angles on both the inherent qualities of carbon composites and the many techniques for its integration into sophisticated engineering uses. Focusing on medical engineering, we combine developments in carbon-c orthocryl resin research in this paper, manufacturing processes, functional applications such reinforce, repair, and produce orthopedic prostheses, and innovative material improvements using nanotechnology, carbon composites are being used more and more in medical and automobile engineering for structural strengthening and repair. Important processes to reduce bond deterioration were found by [1], who also offered an in-depth analysis on bonded carbon-composite/steel systems. This is absolutely vital for the lifetime of strengthened structures. Alongside this, [2] and [3] looked at pragmatic uses of composites advancements in fortifying both new and retrofitted buildings. Researches on the repair and rehabilitation of masonry structures [4] and steel components [5] underline even more the function of carbon composites in prolonging service lives and satisfying more load requirements. These findings highlight that carbon-epoxy is absolutely necessary for modern civil engineering infrastructure since its lifetime and fatigue resistance [6]. In fields such as fire safety improvements, composites have also evolved into multifunctional materials.

By [7] Also combined developments in via unique flame-retardant techniques, hence extending the application possibility of these composites in safety-critical settings. Particularly in the aerospace and automotive industries, where accuracy and low damage are vital, developments in manufacturing technology and processing techniques have greatly affected CFRP's use. Described by [8] and [9], laser processing methods offer non-contact, high-quality machining options that address typical problems, including delamination and burr formation. [10] Also underlined smart machining techniques such as data-driven prediction and optimization, therefore demonstrating the changing power of combining machine learning with conventional production methods. Essential for aerospace component manufacturing and other high-value industrial applications, these methods enable improved surface quality and higher production rates. Recent research on material improvement has focused on adding nanoparticles to enhance the interfacial properties of carbon composites. By [11] Examined how the inclusion of metal nanomaterials, silicon-based, and carbon-based nanoparticles can greatly increase mechanical characteristics, impact resistance, and fiber-matrix adhesion. At the same time, [12] offered a methodical summary of microscopic characterization techniques—including SEM, TEM, and AFM—that are absolutely vital for interpreting the intricate interfacial interactions in these nano-modified composites.

These developments open the door to next-generation composites with customized properties for specific uses by improving structural integrity at the micro-scale. Long-term performance and safety are still highly dependent on inspection and quality assurance of carbon-composite components. Presented by [13], ultrasonic testing methods allow thorough flaw detection and offer a foundation for smart nondestructive evaluation tools. Ultrasonic wave propagation in CFRP composites provides vital information on internal delamination and other damage types, thereby enabling a robust framework for maintenance plans and lifecycle management. tool geometry has also been highlighted as a key factor where traditional twist drills may produce too much thrust, causing more delamination in comparison to specially designed tools like tapered drill-reamers or drills with optimized point angles [14-16]. Though with varying success, as mechanisms such as chip evacuation and heat buildup become important during drilling operations, these sophisticated geometries aid in lowering the critical axial force, thereby controlling the onset of delamination [17]. Creative drilling techniques, including ultrasonic vibration-assisted drilling, have also been proposed as promising ways to reduce mechanical loads and thermal effects that contribute to delamination. By reducing chip adhesion and local heating, these methods improve the integrity of drilled holes. Our research is founded on the application of the SEM to examine the various degradation facies of the samples. We aim to identify several forms of degradation and their influence on the material's lifespan through micrographs at suitable magnifications.

II. THEORETICAL REFERENCE

II.1 MATERIALS AND METHODS

II.1.1 Plate Moulding

The fabrication of a carbon-c-orthocryl plate for the manufacture of orthopedic prostheses is a challenging process. Even after the molding process is complete, the final plates require machining for assembly. The study we used in this study was conducted on a 2*2 twill weave carbon fiber with a Weave of 245 g/m. For the matrix we used a special c-orthocryl resin designated for carbon fiber tissue and with hardener (112P33), one unidirectional plate 100*50 cm were made by infusion molding under 0.8 Bar pressure Fig.1, 8 layers of the fabrics the obtained thickness of the laminates was h=3 mm, the laminates were cured at room temperature for 24 hours, then at 60 c°, For 6 hours.

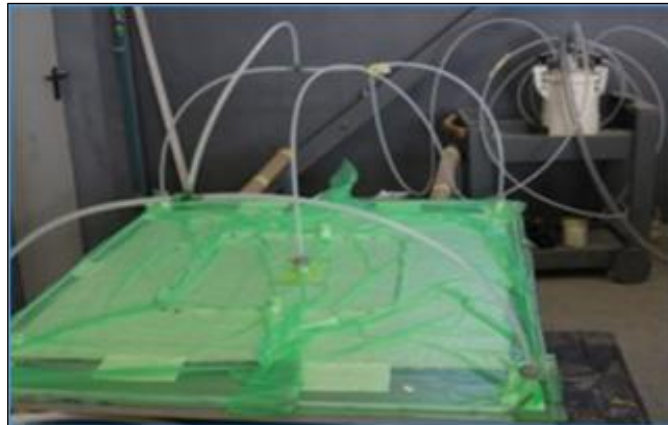


Figure 1: Infusion moulding.
Source: Authors, (2026).

II.1.2 Protocol

After polymerization, the plates were cut into parallelepiped specimens of 220x30x2 mm³ and drilling process is conducted using HSS twist drill-bit with a constant speed and feed rate $v=900$ rpm. Delamination occurs at the entrance, exit, and even inside the hole (Fig. 2), making the drilling process more prone to various defects [18]. The major defects are directly related to the cutting tool's initial impact on the fiber-matrix interface, leading to delamination that starts at the hole entrance. At the exit, however, the sudden loss of support causes fiber pull-out and crack propagation, therefore causing significant damage [19], [20]. Table 1 summarizes the material's characteristics.

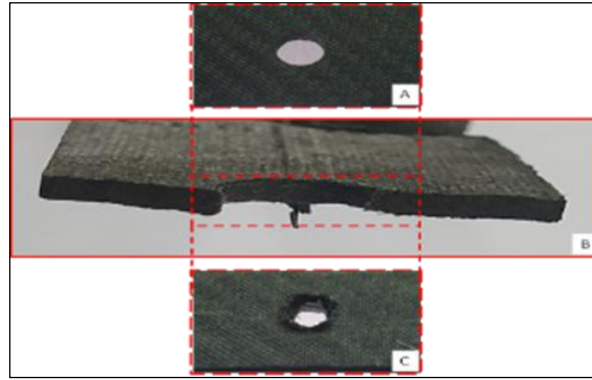


Figure 2: Drilled specimen A: entry of the hole (peel-up), B: inside hole, C: exit of the hole (push-down).
Source: Authors, (2026).

Table 1: Material characteristics.

Fiber	Weaving	Surface density [g/m ²]	Mass fraction [%]	Supplier
Carbon	taffeta	300	35	
Resin	Layer	Weight[g]	Dimension [mm ³]	
Epoxyc-orthocryl	3	12	220*30*2	Otto bock Germany

Source: Authors, (2026).

II.1.3 Microscopy

To achieve an absolute understanding of delamination during the drilling of this composite, SEM analysis with assistance (Machine MEB) was performed. Specimens were carefully cut from the drilled area of all holes using an HSS twist drill to ensure minimal marks were generated during cutting and provide a clear imaging surface. or image acquisition, a Quanta 250 In Fig. 3, SEM images were acquired in black scattered electron, the SEM images were treated using TrackerLab, the images were converted to grayscale, and the ellipse mask was applied to the region of interest.



Figure 3: SEM electronic microscopic Quanta 250.
Source: Authors, (2026).

We cut the control specimen in the longitudinal, transverse, and frontal directions (Figure 4). This cutting allows us to assess the material's internal structure and detect possible moulding defects and fiber-resin compatibility.

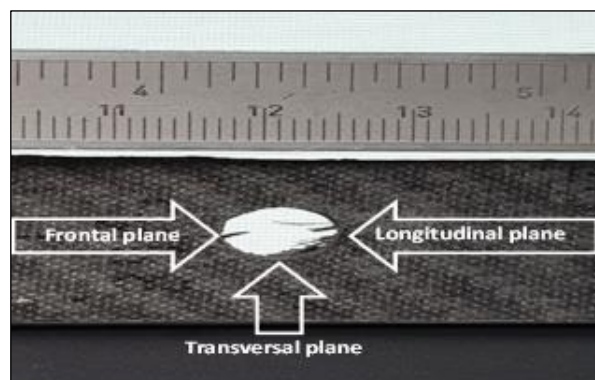


Figure 4: Different planes according to the cross-sectional planes of the drilled hole.
Source: Authors, (2026).

III. RESULTS AND DISCUSSION

III.1 DELAMINATION IN THE DIFFERENT PLANES

III.1.1 Frontal Plane

The obtained SEM images illustrate the different damage occurring in the carbon-c-orthocryl composite at multiple locations during drilling, highlighting intralaminar delamination and matrix tearing. Fig.5, magnified at 160x, displays considerable intralaminar delamination on the fracture surface inside the hole. The differences between separate laminates are apparent, marked by the visibility of aligned fiber bundles and by disruptions in matrix homogeneity. The delamination appears to align with the fiber direction, suggesting that the matrix distribution between the plies or within the matrix was weakened during drilling. The significant fiber pull-out and the existence of the hole fibers suggest that fracture propagation was mainly observed along the weak interlaminar planes, which is characteristic of multilayer composites subjected to out-of-plane or interlaminar loading. Furthermore, matrix tearing occurs at various regions surrounding the fiber bundles. These zones display a damaged, fractured appearance, indicating that the resin matrix failed to maintain its cohesiveness during crack propagation. The c-orthocryl resin's brittleness is indicated by the direction of the fracture caused by the drill bit. Fig. 6, taken at a lower magnification (56x), provides a broader perspective of the composite structure at the level of the hole entry. Larger-scale delamination at this, characterized by the separations and damages aligned with the fiber orientation. this macro-level damage corresponds with standard intralaminar delamination failure modes, where the anisotropic characteristics of the composite influence crack propagation [16] confirmed this is related to thrust force applied during the drilling, also the matrix regions exhibit increased degradation, characterized by matrix cracking and longitudinal tearing, understanding that the brittle fracture characteristic of the matrix under stress. The smooth portions between fiber-resin areas show a good cohesion between the plies. At the same time, Fig.7 displays delamination ant the exit it appears noticeable, indicating the separation of the bottom most layers, collectively, these SEM pictures illustrate the initiation and propagation of intralaminar delamination along weak planes inside the composite, by matrix tearing, which acts as a mechanism for energy distribution but ultimately results in a catastrophic loss of structural integrity when drilling. The observations align with failure scenarios in fiber-reinforced composites under high-stress or impact loading, where matrix-dominated failures predominate over fiber failures.

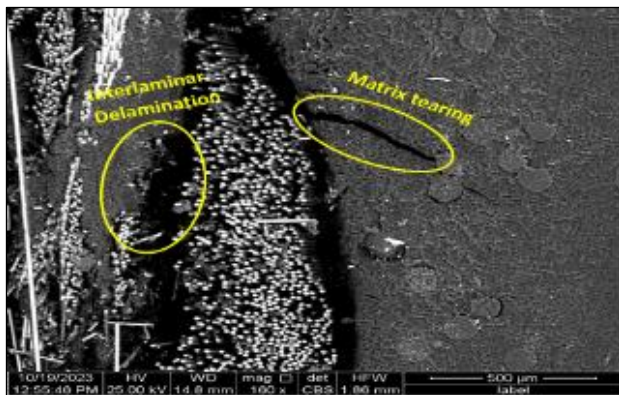


Figure 5: SEM Image for frontal plane inside hole at 160X.
Source: Authors, (2026).



Figure 6: SEM Image for frontal plane hole entry at 56 X
Source: Authors, (2026).

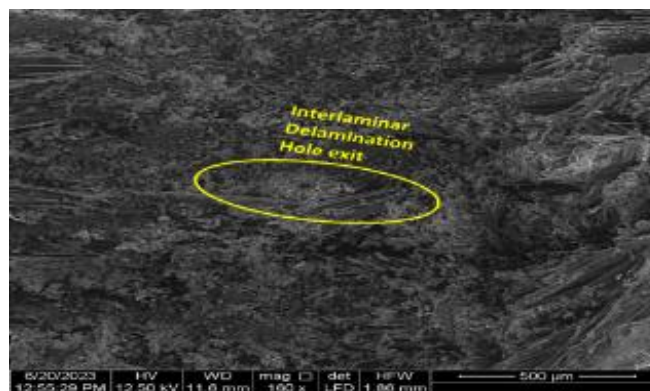


Figure 7: SEM Image for frontal plane hole exit at 160X
Source: Authors, (2026).

III.1.2 Longitudinal Plane

The longitudinal plane micrographs show an intralaminar delamination as a critical damage in the carbon-c orthocryl composite across all images. An intermediate stage of delamination, in which several fiber layers are separated but remain partially connected by broken fibers within a hole, is shown in Fig. 8 (120×). While Fig. 10 taken at a higher magnification (300×) offers a detailed view of the crack network and exposed fibers at the exit of the hole, emphasizing the microstructural roughness caused by progressive damage, Fig. 8 (60×) shows the large scale of intralaminar delamination and the general fiber tearing morphology at the level inside hole .

Large fractures between inside fiber layers in Fig.8 and Fig.10 point to separation inside the laminate rather than complete interfacial fiber-matrix debonding. When the matrix toughness is too low to resist fracture initiation and propagation under mechanical stress, a common feature is the separation propagating along the weak matrix-rich interlaminar regions. The widespread, random voids point to slow delamination, beginning with matrix microcracking and accelerating under greater thrust force [21]. This was explained due to stress concentration generated by the drill bit. Fig. 8, which shows lower magnification, clearly shows a weakened overall integrity of the laminate, as it exposes multiple delamination planes, producing a broken appearance. Fig. 8 and Fig. 9 reveal fiber ripping, where fiber bundles are damaged and pushed out at the hole exit. The fibers suggest they were under significant shear stress before collapse, as evidenced by ragged rather than smooth fiber breakage. This suggests that the fiber-matrix contact initially resisted debonding, directly transferring weight to the fibers until they tore rather than causing brittle fracture. The broken fibers in Fig. 8, which project unevenly from the delaminated areas, underscore that the fibers' load-bearing capacity contributed to the fracture resistance up to the point of failure. Fig. 10 also shows some fiber ends exposed along the fracture paths, thereby supporting the idea that fiber rupture occurs parallel to matrix cracking and delamination.

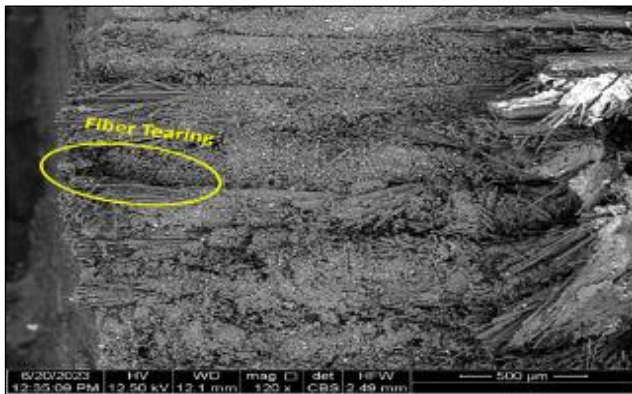


Figure 8: SEM Image for Longitudinal plane inside hole at 120X.
Source: Authors, (2026).

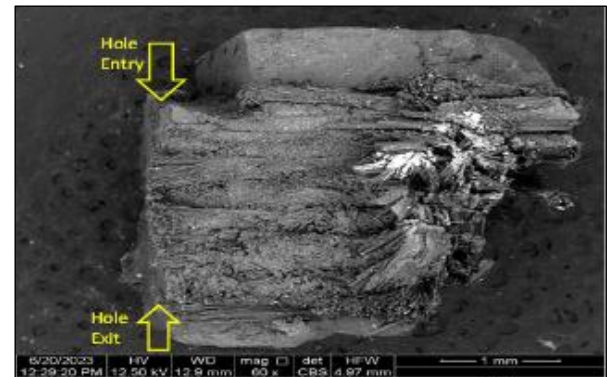


Figure 9: SEM Image for Longitudinal plane at 60X.
Source: Authors, (2026).

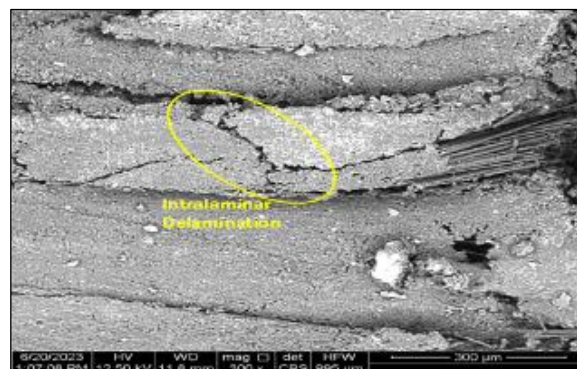


Figure 10: SEM image for Longitudinal Plane hole exit at 300X.
Source: Authors, (2026).

III.1.3 Transversal Plane

Clear signs of translaminal delamination are seen in Fig. 11 and Fig. 12 at the hole entry and inside the hole, unlike intralaminar delamination, which follows the plane between layers. On the other hand, translaminal delamination cuts through both the matrix and the fiber bundles, usually perpendicular or at angles to the principal laminate planes and drilling direction. With delamination planes spanning the thickness of the composite, several fiber bundles appear to have been displaced and split under 80× magnification in Fig. 11. The sharp boundaries between fiber-rich and matrix-rich regions imply that the fracture ran through the entire composite structure, cutting through both fiber and matrix phases. Where fiber bundles exhibit obvious symptoms of vertical cracking across their thickness, Fig. 12 (200× magnification) offers a closer view of the broken cross-section. This translaminal cracking suggests that the crack energy was sufficient to fracture not only the matrix but also to enter the fiber tows, thereby fostering deep-seated delamination routes. Figures 12 and 13 show clear matrix decohesion, especially around the damaged fiber bundles at the interface, inside, and at the hole exit, notable voids and rough matrix surfaces are seen in Fig. 13 (200x magnification). This structure shows matrix cracking and decohesion, a failure mode in which excessive stress concentration or bad adhesion causes the c-orthocryl resin to separate from the supporting fibers. By [22] highlighted this during the fiber pull-up the due to energy dissipation generated by the drilling while [23] on the other hand demonstrated that the traslaminar delamination at pull-out in thin ply composites occurs crucially when the drill bit exit the last ply, relatively flat matrix surfaces and fiber imprints left behind verify that adhesive failure at the fiber-matrix contact have place. Moreover, places where the matrix seems to have cracked or separated from fibers show the low energy absorption capacity of the matrix under drilling stress, leading to the beginning of decohesion.

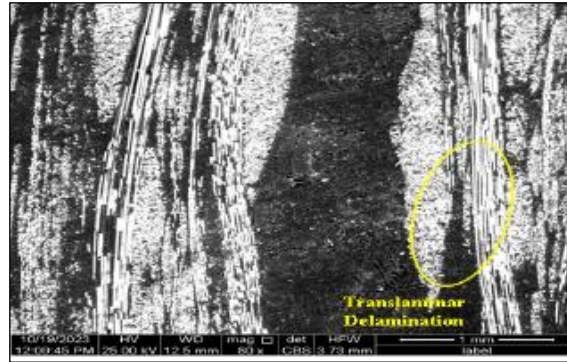


Figure 11: SEM image for transversal plane hole entry at 80X.
Source: Authors, (2026).

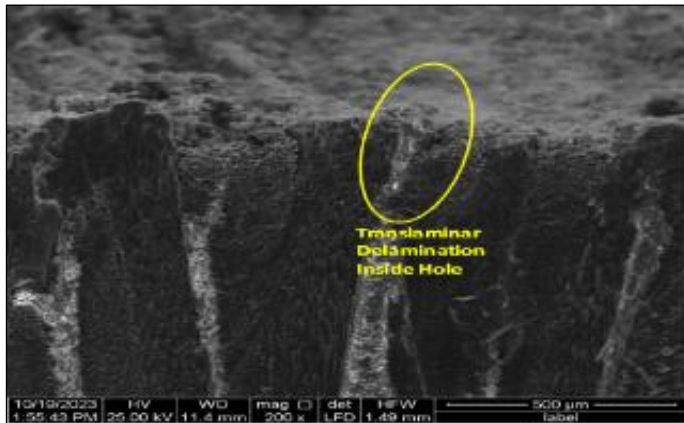


Figure 12: SEM image for the transverse plane inside the hole at 200X.
Source: Authors, (2026).

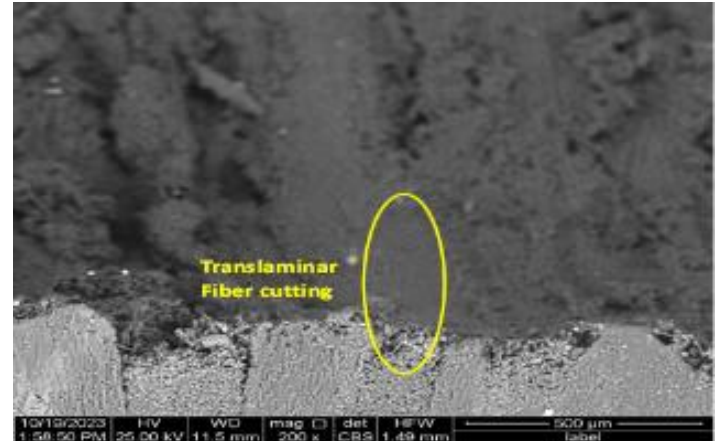


Figure 13: SEM image for transversal plane hole exit at 200 X.
Source: Authors, (2026).

IV. CONCLUSIONS

Drilling-related stresses mostly produce microdamages observed in the SEM analysis of the carbon-C-orthocryl composite across the frontale, longitudinal, and transversal planes. On the frontale plane Large interlaminar delamination in line with fiber orientations and significant matrix tearing in the frontale plane reveal the carbon-c orthocryl composite sensitivity to the drilling operation inside the hole and a the exit, straining the brittle matrix due to drilling induced thrust and shear force. the longitudinal plane micrographs draw attention to intralaminar delamination even more, so implying that inadequate matrix toughness generated slow but wide damage spread by means of progressive fiber tearing and matrix cracking. In the transverse plane, translaminar delamination predominated; cracks spreading across matrix regions and fiber bundles indicated that the fracture energy from drilling operation was sufficient to permeate both phases of the material. Moreover, the results indicate that matrix-dominated failures via matrix tearing, decohesion, and fiber ripping are quite significant for the overall drop in structural integrity during drilling operations in carbon-c-orthocryl composites.

V. AUTHOR'S CONTRIBUTION

Conceptualization: Farouk Mesrafet, Younes Menail and Djaber Bouhafara.

Methodology: Farouk Mesrafet, Younes Menail and Djaber Bouhafara.

Investigation: Farouk Mesrafet, Younes Menail and Djaber Bouhafara.

Discussion of results: Farouk Mesrafet, Younes Menail and Djaber Bouhafara.

Writing – Original Draft: Farouk Mesrafet, Younes Menail and Djaber Bouhafara.

Writing – Review and Editing: Farouk Mesrafet, Younes Menail and Djaber Bouhafara.

Resources: Farouk Mesrafet, Younes Menail and Djaber Bouhafara.

Supervision: Farouk Mesrafet, Younes Menail and Djaber Bouhafara.

Approval of the final text: Farouk Mesrafet, Younes Menail and Djaber Bouhafara.

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